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Do mirror planets exist in our solar system?

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ABSTRACT

Mirror matter is predicted to exist if parity is an unbroken symmetry of nature. Currently, there is a large amount of evidence that mirror matter actually exists coming from astrophysics and particle physics. One of the most fascinating (but speculative) possibilities is that there is a significant abundance of mirror matter within our solar system. If the mirror matter condensed to form a large body of planatary or stellar mass then there could be interesting observable effects. Indeed studies of long period comets suggest the existence of a solar companion which has escaped direct detection and is therefore a candidate for a mirror body. Nemesis, hypothetical "death star" companion of the Sun, proposed to explain biological mass extinctions, may potentially be a mirror star. We examine the prospects for detecting these objects if they do indeed exist and are made of mirror matter.

Subject headings: dark matter – stars: individual (Nemesis)

One of the most interesting candidates for dark matter coming from particle physics is "mirror matter". Mirror matter is predicted to exist if parity is a symmetry of Nature (Lee and Yang 1956, Kobzarev et al. 1966, Pavšič 1974, Foot et al. 1991). The idea is that for each ordinary particle, such as the photon, electron, proton and neutron, there is a corresponding mirror particle, of exactly the same mass as the ordinary particle. The fundamental interactions of the mirror particles precisely mirrors those of the ordinary particles. For example, the mirror proton interacts with the mirror photon in precisely the same way in which an ordinary proton interacts with an ordinary photon. The mirror particles are not produced in laboratory experiments just because they couple very weakly to the ordinary particles. In the modern language of gauge theories, the mirror particles are all singlets under the standard $G \equiv SU(3) \otimes SU(2)_L \otimes U(1)_Y$ gauge interactions. Instead the mirror particles interact with a set of mirror gauge particles, so that the gauge symmetry of the theory is doubled, i.e. $G \otimes G$ (the ordinary particles are, of course, singlets under the mirror gauge symmetry) (Foot et al. 1991). Parity is conserved because the mirror particles experience $V + A$ mirror weak interactions and the ordinary particles experience the usual $V - A$ weak interactions. Ordinary and mirror particles interact with each other predominately by gravity only.

While mirror matter has always been extremely well motivated theoretically, it is only in relatively recent times that the experimental and observational evidence for it has accumulated to the point where an impressive case for its existence can be made (for a review of the current status of mirror matter, see Foot 2001b). First, it provides a natural candidate for dark matter. Mirror matter is naturally dark and stable and appears to have the necessary properties to explain the dark matter inferred to exist in the Universe (Blinnikov and Khlopov 1982, 1983, Kolb et al. 1985, Khlopov et al. 1991, Hodges 1993, Matsas et al. 1998, Bell and Volkas 1999, Berezinsky and Vilenkin 2000, Berezhiani et al. 2000). On galactic scales, there is evidence from a recent weak microlensing study (Erben et al. 2000, Gray et al. 2001) for large clumps of invisible matter which might be a mirror galaxy (or galaxy cluster) (Foot 2001b). Within galaxies such as our own Milky way, mirror matter may be the dominant component of the halo, thereby explaining the MACHO observations (Silagadze 1997, Blinnikov 1998, Foot 1999, Mohapatra and Teplitz 1999) [1]. On small scales (such as solar system scale) systems containing ordinary and mirror matter could exist but it is likely that they should be quite unequally mixed (e.g. 99% ordinary matter and 1% mirror matter). This is because ordinary and mirror matter are naturally segregated on small scales as they don't have common dissipative interactions (Blinnikov and Khlopov 1982, 1983, Kolb et al. 1985, Khlopov et al. 1991). In fact, the strange properties of some of the extrasolar planets may be explained more naturally if they are mirror planets (Foot 1999b, 2001a). Furthermore, recent Hubble Space Telescope star count results show the deficit of local luminous matter (Blinnikov 1999, 2000; However there is some controversy with Hipparcos satellite data, see Holmberg and Flynn 1998), expected if the population of the mirror stars in the galactic disk is numerous enough (Blinnikov and Khlopov 1982, 1983).

On quite a different tack, there is evidence for mirror matter coming from the solar and atmospheric neutrino anomalies (Foot et al. 1992, Foot 1994, Foot and Volkas 1995. For a review of the neutrino physics anomalies, see e.g. Langacker 1999). Ordinary and mirror neutrinos are maximally mixed with each other if neutrinos have mass (Foot et al. 1992, Foot 1994, Foot and Volkas 1995). The maximal $\nu_e \to \nu'_e$ (the $'$ denote the mirror particle) oscillations predict an approximate 50% ν_e flux reduction thereby explaining the solar neutrino experiments while the maximal $\nu_\mu \to \nu'_\mu$ oscillations predict the up-down neutrino asymmetry observed in Super-Kamiokande (Fukuda et al. 1998a, 1998b) (see e.g. Foot et al. 1998, Foot 2000, Fornengo et al. 2000 for a fit of maximal $\nu_\mu \to \nu'_\mu$ oscillations to the data). The idea is also compatible with the LSND experiment (Foot et al. 1992, Foot 1994, Foot and Volkas 1995). Interestingly, maximal ordinary - mirror neutrino oscillations do not pose any problems for big bang nucleosynthesis (BBN) and can even fit the inferred primordial abundances better than the standard model (Foot and Volkas 1997, 2000).

Finally there are several other interesting effects of mirror matter which have been discussed such as photon - mirror photon kinetic mixing (Holdom 1986, Glashow 1986, Carlson and Glashow

[1] The conventional red, brown or white dwarf interpretation of these MACHO events have real problems (see e.g. Freese et al. 1999). It is also possible that the MACHO events are due to lens in the LMC (and not actually in the halo of our galaxy), however this interpretation also is problematic (see for example, Gyuk et al. 1999).

1987, Collie and Foot 1998), Higgs - mirror Higgs mixing (Foot et al. 1991, H. Lew, unpublished) and possible ordinary - mirror particle interactions (Silagadze 1999) expected in currently popular models of large extra dimensions (Akama 1982, Rubakov and Shaposhnikov 1983, Arkani-Hamed et al. 1998). It should also be noted that there are variants of the mirror matter idea where the mirror symmetry is assumed to be spontaneously broken (Barr et al. 1991, Akhmedov et al. 1992, Foot and Lew 1994, Berezhiani and Mohapatra 1995, Berezhiani et al. 1996, Berezhiani 1996, Mohapatra and Sciama 1998, Lindebaum et al. 2000).

Given the possibility that many nearby stars have "hot jupiters", which may really be "cool mirror planets", it is possible that there are also mirror stars/planets/comets etc gravitationally bound to our sun. Of course, any very nearby large planet would have been detected via its gravitational influence. A more distant companion is a priori a fascinating possibility. In fact there is some evidence for the existence of such objects from biological mass extinctions and recent studies of long period comets as we now discuss.

Over the past 15 years or so there has been speculation that there is a companion star to the sun, called "Nemesis" (Whitmire and Jackson 1984, Davis et al. 1984). The motivation for Nemesis was based on studies suggesting that biological mass extinctions displayed some periodicity (on a time scale of about 26 million years) which required an extraterrestrial cause (Raup and Sepkoski 1984). It was also argued that the ages of craters displayed a similar periodicity (Rampino and Stothers 1984, Alvarez and Muller 1984). The idea is that Nemesis would have a moderately eccentric orbit with an orbital period of 26 million years, which would periodically disturb the Oort cloud and cause comets to enter into the inner solar system and trigger the mass extinctions. Subsequent searches for Nemesis failed to find it (Perlmutter 1986) and also some studies suggested that its orbit was likely to be unstable (see e. g. Clube and Napier 1984). However if the orbit is near the galactic plane, the *current* Nemesis's lifetime can be as big as 10^9 years (Hut 1984, Torbett and Smoluchowski 1984, Vandervoort and Sather 1993). This lifetime is not long enough for Nemesis to have been in such a large orbit at the formation of the solar system, about 5×10^9 years ago. However at the formation of the solar system, at which time Nemesis was also presumably formed, the orbit may have been much tighter, expanding to the present orbit as a consequence of tidal perturbations from passing stars and molecular clouds (Hut 1984). It has been argued that the perturbations by gigantic molecular clouds may be the most serious threat for stability of Nemesis (Clube and Napier 1984), but it has also been argued that the very diffuse nature of these massive clouds greatly reduces the possible effect (Morris and Muller 1986).

Recently, new much more direct evidence for planetary or stellar companions to the sun has also emerged. Two groups (Murray 1999, Matese et al. 1999) have studied the orbits of long period comets. They find that there is a statistically significant excess of aphelion distances of long-period comets aligned on a great circle (for comets in the 30k-50k A.U. range). The approach of the two groups was quite different, with the Murray 1999 taking a subsample of the most accurately observed long period comets while Matese et al. 1999 used a larger sample, but included less well observed comets. Apparently, the two groups find somewhat different great circles, which can mean several things. It might mean that there are two companions, or only one companion (if one of the groups is mistaken) or no such companion (if they both screwed up). For example, the study of Murray 1999 finds that the data suggests the existence of a large planet or star with orbital period of around 6 million years (which implies a distance from the sun of about 32000 A.U. for a circular orbit). The analysis suggests that the orbital plane of the companion planet/star was inclined at roughly 35^o to the galactic plane with a retrograde orbit. Interestingly, both of these characteristics, the relatively low inclination to the galactic plane and the retrograde orbit were already identified as necessary conditions for the stability of such orbit (Hut 1984, Torbett and Smoluchowski 1984, Vandervoort and Sather 1993). Thus, it seems to be possible that the hypothetical planet/star identified in Murray 1999 was an original member of the solar system. Clearly, further data should clarify whether such companions really exist.

If companion stars/planets do exist, then it is possible that they are light enough to be below the hydrogen burning threshold and may have escaped detection. However, another possibility is that the companion objects may be made of mirror matter (the possibility that Nemesis exists and is made of mirror matter was earlier discussed in Silagadze 2001 [2]). This will give a simple explanation for why their orbital plane is inclined with respect to the ecliptic (naturally, tidal perturbations may have modified their orbits somewhat over time too). Indeed, because ordinary and mirror matter couple together mainly by gravity, it is natural for the ordinary and mirror parts of nebula (from which the solar system was made) to have different initial conditions, like angular momentum. If the galaxy contains a significant amounts of mirror matter, such mixed protosolar nebula can be formed, for example, during inter-penetration of ordinary and mirror giant molecular clouds (Khlopov et al. 1991).

Of course it is certainly true that if there is a mirror matter companion within our solar system then its existence will be challenging to establish. Nevertheless it is important to keep in mind that this possibility, which might be true, is in principle a testable hypothesis!

First of all let us mention some indirect checks. If the Sun-Nemesis constitute a mixed binary system there will be other similar star systems around. We have already mentioned strange properties of some recently observed extrasolar planets and their interpretation as mirror planets orbiting ordinary stars (Foot 1999, 2001a). One can imagine a reversed situation: an ordinary planet orbiting mirror star. Remarkably eighteen "isolated planetary mass objects" were actually discovered (Zapatero Osorio et al. 2000, Lucas and Roche 2000; See also Tamura et al. 1998) in σ Orionis star cluster. Instead of being really isolated, which will challenge conventional theories of planet formation, these objects could be ordinary Jovian type planets orbiting invisible mirror stars (Foot et al. 2000a). This idea can be tested by searching for a periodic Doppler shift of absorption lines

[2]The possibility that the protosolar nebula could contain "shadow" matter and its evolution could lead to the formation of some mirror solar objects, like Nemesis, was also mentioned in Kolb et al. 1985. But this idea was not further developed in Kolb et al. 1985 and even taken seriously, because it was thought that big bang nucleosynthesis data excludes the "shadow world" with completely symmetric microphysics.

in the planet emanation spectra (Foot et al. 2000a), or/and by Planetary Microlensing technique (Mao and Paczyński 1991; For recent review see Sackett 1999).

Photon-mirror photon mixing can effect the orthopositronium lifetime (Glashow 1986) and lead to an interesting resolution of the orthopositronium lifetime puzzle (Foot and Gninenko 2000). If the mixing parameter has indeed the magnitude required for the mirror world interpretation of the orthopositronium anomaly (and this will be experimentally tested in future vacuum cavity experiments), a new window will be opened in mirror matter searches in the solar system. As mirror meteoroids would effectively interact with Earth's atmosphere in this case, releasing most of their kinetic energy in the atmosphere and possibly ending in atmospheric explosion (Foot 2001b, Foot and Gninenko 2000). In such "Tunguska-like" events neither meteoroid fragments nor any significant crater would be found. Also, any ordinary matter accreted onto the mirror companion can potentially become hot due to the coupling of mirror matter to ordinary matter via the photon -mirror photon mixing. This may make the mirror companion potentially observable (and may be appear to have the characteristics of a strange type of white dwarf, especially if the companion object is of stellar weight) (Foot et al. 2000b).

Another means of investigating the Nemesis hypothesis is provided by exploration of cratering rates of the nearby celestial bodies such as the Moon and the Mars. It was argued (Muller 1993) that the age distribution of craters on the Moon can be studied by using lunar spherulus. A pilot study had been already performed (Culler et al. 2000) using 155 spherulus from the lunar soil delivered by Appolo-14 mission. The results are promising. From 3 Gyr ago until about 0.4 Gyr ago the inferred cratering rate gradually decreases. This is consistent with expectation that the density of potential impactors (asteroids and comets) should decrease as time goes by, because Jupiter slowly eliminates them by deflecting them into the Sun or ejecting them out of the solar system. At 0.4 Gyr, however, the rate suddenly increases by a factor of 3.7 ± 1.2 and returns to the level it had 3 Gyr earlier. This fact has "a ready explanation" (Culler et al. 2000) in the framework of the Nemesis hypothesis. One can imagine that just about 0.4 Gyr ago the Nemesis was perturbed into a more eccentric orbit by a passing star, thus becoming able to approach the Oort cloud closely at every subsequent perihelions and trigger comet showers.

The median age uncertainty, achieved thus far in the lunar spherule project, is about 150 Myr not sufficient to resolve a 26 Myr periodicity – the main prediction of the Nemesis hypothesis. But future similar studies will hopefully reach the necessary precision. If the 26 Myr periodicity in cratering rates is unambiguously established but the Nemesis nevertheless is not found in future parallax surveys of the stars as dim as 10th magnitude (the Hipparcos satellite surveyed only about 1/4 of the known candidates (Culler et al. 2000)), the mirror option will get strong support.

Even if mirror solar companions exist and are invisible, then their existence could still be confirmed! Even completely dark compact gravitating objects reveal themselves through the gravitational lensing effect they produce on background stars (Paczyński 1997, Roulet and Mollerach 1997). It is expected that Space Interferometry Mission (SIM), planned to be launched in 2005, will allow a determination of the mass, the distance, and the proper motion of virtually any MACHO capable of inducing a microlensing event (Miralda-Escudé 1996, Paczyński 1998). For putative microlensing event due to Nemesis the angular Einstein ring radius would be (Paczyński 1998)

$$\varphi_E \approx 90 \text{ mas} \sqrt{\frac{M_N}{M_\odot}} \sqrt{\frac{1 \text{ pc}}{D_N}} \, ,$$

where M_N is the Nemesis mass and D_N the distance to it. Thus it will be resolved by SIM which is expected to have angular resolution of about 10 mas. Therefore if such a microlensing event is really detected, it will give a very detailed information about Nemesis. The only problem is that because the present position of the Nemesis is unknown we are forced to relay merely on a chance to discover the event or perform a full sky dedicated search for it.

Whether or not mirror matter exists will become clearer as time goes by. In the mean time, it is fun to think about the implications of fascinating possibilities such as mirror planets in our solar system. In addition to the (admittedly very speculative) evidence for faint solar companions provided by observations discussed above, it is also possible that some other much closer and smaller mirror planet can also exist. Over time, if its orbit is eccentric enough, such planet can approach to various "normal" solar planets and cause observed oddities in the solar system, like Pluto's orbit. We can also speculate that the formation of the Moon was a result of tidal fission of the Earth caused by a close encounter with a mirror planet.

But speculations apart, the hypothesis that there are some mirror objects in the solar system is in principle testable hypothesis, because these mirror objects can lead to observable effects due to their gravitational interactions and they may also observably radiate if they contain enough ordinary matter.

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